Frontier of Statistical Physics and Information Processing 2013

Internal dissipation-free model for F_1-ATPase

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F_1-ATPase is a reversible rotational molecular motor, which is known to convert Adenosine Triphosphate (ATP) hydrolysis free energy into mechanical work with maximum efficiency [1]. Recent experiments have further revealed an interesting property of F_1-ATPase; the dissipative heat inside the motor ($Q_{\rm int}$ in figure) is very small, irrespective of the velocity of rotation [2]. This means that most of the chemical free energy is dissipated through the rotational degree of freedom of the γ-shaft ($Q_{\rm ext}$). From the theoretical point of view, the amount of the internal dissipation is not simply determined by the detailed balance condition, but also relies on the rotational-angular dependence of the affinity to the chemical fuel [3]. One is therefore tempted to believe that there is a generic design principle behind such fine tuning.

In this presentation, we show a model that explains the low internal dissipation [4]. The key observation is that the passive affinity model, where the ATP binding to F_1 has low dependence on the angle of the γ shaft, shows features that are most consistent with experimental results. Theoretical analysis proves the crucial role of two time scales in this model, corresponding to internal-dissipation vanishing and rotational-speed saturating ATP concentrations. The low velocity dependence of the internal dissipation observed in experiment is explained in terms of the large separation between these two time scales. The assumption we make on the anglular dependence of the switching rate is simple, and could be tested in future experiments. We expect that such mechanism to minimize the dissipation is a universal feature in molecular motors, and an important principle in designing machines at the thermal-fluctuation dominated scale.

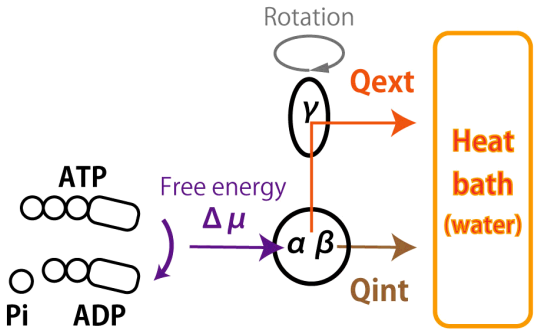

Figure 1: Schematic of the energy income and outflow in F_1-ATPase.

[1] S. Toyabe, et al., PNAS, 108, 17951 (2011).
[2] S. Toyabe, et al., PRL, 104, 198103 (2010).
[3] E. Zimmermann, and U. Seifert, NJP, 14, 103023 (2012).
[4] K. Kawaguchi, S.-I. Sasa, and T. Sagawa, to be submitted.